BULLETIN
No. 5

SCIENTIFIC ROAD CONSTRUCTION

The movement for good roads is attracting world-wide attention. The object of this bulletin is to call attention to the fundamental principles of road building, and the necessity for the thorough examination of the materials used in road construction.

Department of Asphaltum

STANDARD OIL COMPANY
(CALIFORNIA)

Grades of Star Asphaltum

Scientific Road Construction

Department of Asphaltum
STANDARD OIL COMPANY
(California)

MODERN TRAFFIC CONDITIONS AND ANALYSIS OF STRESSES.

The character of modern traffic has altered considerably in the last ten years. Roads are now subjected to greater maximum loads by the use of traction engines and heavier trucks. Loads are carried more rapidly by auto-trucks and heavy touring cars. From these conditions, new road problems have arisen.

A road, street or highway is a structure built to withstand the stresses imposed by traffic and climatic forces.

The main stresses are due to:

1—Forces caused by dead and live loads.
2—Forces caused by impact.
3—Forces caused by shearing.
4—Forces caused by suction.
5—Forces caused by climate.

1—Dead and Live Loads: These forces act downward as compression and tend to force the road into the sub-soil thus forming depressions. The road must have strength and rigidity enough to distribute these loads to the sub-soil in a safe manner.

2—Impact: This force is created by a shock or blow given by a vehicle, automobile or horse and varies in intensity; the intensity varies with the weight and velocity of the moving body. The effect is to disintegrate the road. Therefore, the road must be able to withstand disintegration. The impact comes on the surface, which must have properties to absorb this force without disintegration.

3—Shearing: This is caused by the tractive force exerted by the driven wheels of an automobile. This force varies as the weight and speed of the vehicle vary. The effect of this force is a disintegration of the surface. Water macadam surfaces, having little resistance to shearing, the road is easily broken and the finer particles thrown into the air.

4—Forces Caused by Suction: Behind the body of any swiftly moving vehicle there is a partial vacuum formed. This force tends to break the bond and dislodge the particles in a road surface, therefore, a bond strong enough to withstand this force must be provided.

5—Climatic Forces are created by variation of temperature, wind and water. Heat causes disintegration by expansion. Cold causes disintegration by contraction, and by freezing the water that is in any voids in the road. Wind blows away loose materials. Water acts chemically on the rock in the road and also sinks through the road, making the sub-soil soft, thus tending to allow the road to sink in such places.

To contend against these forces there must be provided a material which will expand and contract under the temperature conditions to which it is subjected without breaking the bond, also the road must be made impervious to water.

To sum up:

1st—For Dead and Live Loads: A base is required that has strength and rigidity. This can be provided for by the use of water macadam, concrete, brick, basaltic blocks, or similar materials.

2nd—For Impact: A material is required to absorb shocks and prevent disintegration.

Asphaltum has this property.

3rd—For Shearing: A material is required to prevent disintegration.

Asphaltum supplies the bond that will prevent disintegration.

4th—For Suction: A material is required that will form a bond and prevent the particles being carried away.

Asphaltum is the best material known.

5th—To overcome climatic forces we must have:

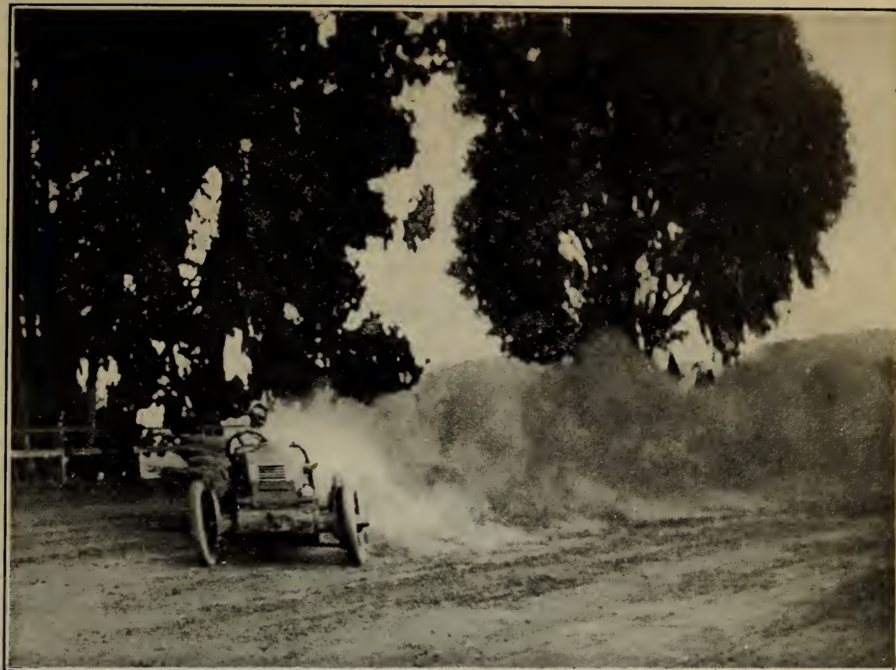
(A) A material with a greater expansion and contraction than rock and one which will prevent the road from disintegrating.

(B) A material which will make the road impervious to water.

Asphaltum fulfills both of these requirements.

Prior to ten years ago, before automobiles became the principal traffic of roads, the main forces on roads were dead and live loads and impact. The speed of vehicles was not great, and therefore, live loads, which depend on velocity, were not great.

Impact is due to horses hoofs and the bumping of wheels over ruts. Impact depends on velocity which at that time was not high. Water macadam roads were developed to meet these conditions. Since the advent of the automobile new forces have developed, such as shearing and suction. These, together with impact, tend to disintegrate the road, as the following picture will show.

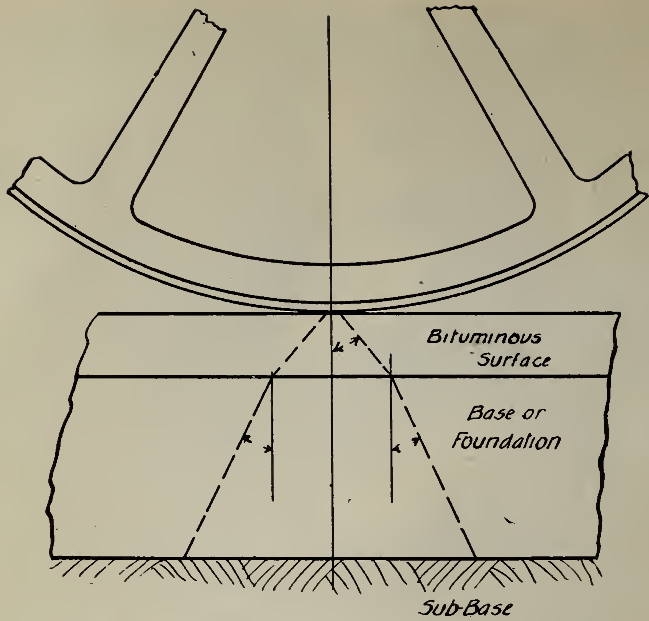


Automobile Rounding Curve

Water macadam has little resistance to shearing or impact and readily breaks up. Rock dust when mixed with water and subjected to the Standard Impact Test, breaks at about 25 blows; when mixed with liquid asphaltum instead of water, breaks at 2000 blows. Under compression the rock dust and water will break at about 350 pounds per square inch, and the liquid asphaltum briquette will break at 300 pounds per square inch.

It can thus be seen that there is a vast difference in the behavior of water macadam and asphaltum under impact and compression. The main forces on a surface cause disintegration by breaking the bond and the difference between 25 and 2000 blows shows the value of asphaltum surfaces as compared with water macadam.

The load on a road is transmitted to the sub-base or earth. The thickness of the road must be such that the load on the sub-base must have a safe limit. Generally speaking, this safe load is 2 to 3 tons per square foot. The angle at which the load is distributed varies with each material, although a mixture of rock and asphaltum distributes the load at a greater angle than water macadam or concrete. Investigation shows that the angle depends on the material and density of mixture. An average value with asphaltum and rock will be 40 degrees, with water macadam or concrete, 25 degrees.



Relative Angles of Distribution of Forces from Wheel

The figure above shows approximately how the load is distributed with asphaltum. When the character of the sub-base and the safe load it will stand, is known, the thickness of the base can be logically determined for the carrying of any definite load.

REASONS FOR FAILURE.

Modern engineering work is conducted in accordance with scientific standards. The use of asphaltum must be approached in the same scientific manner. If not approached in this manner the road may fail for the following reasons:

Sub-base non-draining.
Sub-base too springy because of organic material.
Sub-base of a material requiring special treatment.
Base not having properly graded material.
Base having material that does not macadamize.
Base having material that is not homogeneous.
Base being too porous.
Material in surface being non-cementing with asphaltum.
Material in surface being improperly graded.
Material in surface being too soft.
Material in surface having too great or too small a percentage of fines.
Material in surface being too round.
Surface layer too thick.
Surface layer with too much asphaltum.
Surface layer with insufficient asphaltum.

Various materials insufficiently mixed.

Various materials insufficiently rolled.

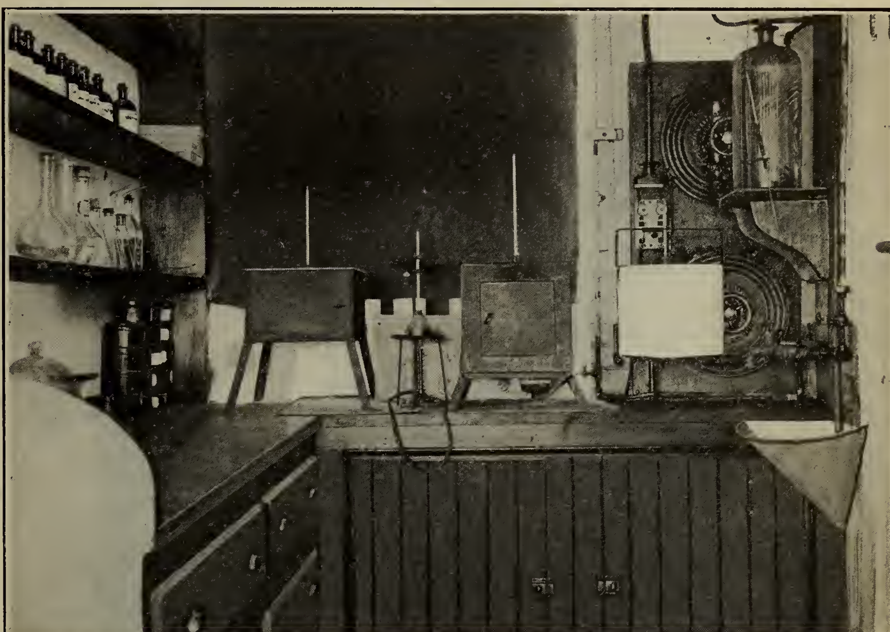
Various layers improperly rolled.

Asphaltum of the wrong grade being used.

Water in the asphaltum.

If the problem is to be solved scientifically, all of these and other material points must be determined in a laboratory, and a specification drawn, based on science and practice.

The Standard Oil Company has approached the problem of road building in this scientific manner. A systematic investigation was made of the principles of road building, and the reasons for deterioration of roads. Many facts have been established and important principles evolved. The



Corner of the Asphaltum Laboratory

Standard Oil Company conducts a laboratory for the exclusive work of research in road and pavement materials, and methods of their construction. The work includes examinations and reports on materials submitted by communities or contractors, and the drawing of specifications based on the results obtained from the examination of the materials.

When materials from defective roads or streets have been examined, specific reasons have always been found for such defects. It has been found that there is great variation in the cementing power of rock and asphaltum. Some rocks will cement especially well with asphaltum and others will cement very poorly.

A certain grading of rock has been found to give a mixture of the greatest density. Roads not built to this grading, tend to weaken and pocket. It has been found that each kind of rock under certain crusher conditions has a crushing characteristic which renders a crusher run of a uniform grade.

Rock coming into the laboratory is graded and tested for general character, hardness, cementing value with water, cementing value with asphaltum, strength under impact, compression and tension, and is subjected to close microscopic examination for identification.

When deciding upon pavement for a street or road there are several points to consider. What will be the cost? What pavement does the traffic require? Is the traffic heavy or light, self-propelled or horse drawn?

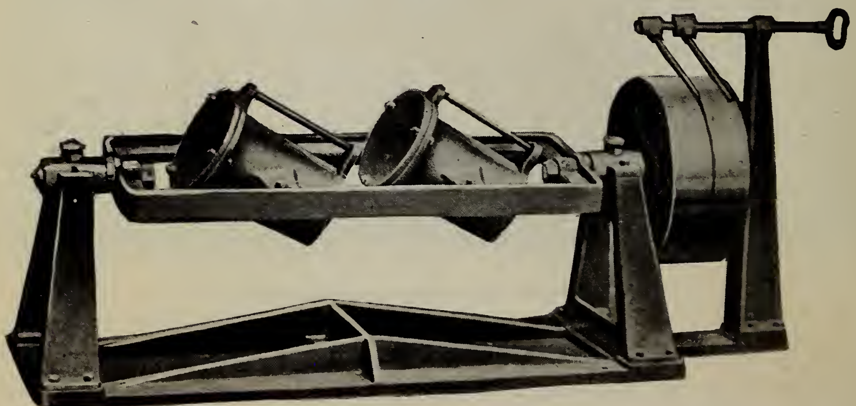
Pavements do not fail as a whole, but through a multiplicity of patches, which finally become so numerous and objectionable that the pavement is condemned. Specifications for maintenance should be as carefully drawn as for the original construction.

MATERIALS.

Good roads cannot be built with inferior materials.

Road materials should have certain properties: Resistance to Wear, Toughness or Resistance to breaking under Impact, Compression Strength, Cementing Quality (both with water and with asphaltum). These properties can be investigated better in a laboratory under standard conditions more accurately and at less cost, than trying out in a road.

The Resistance to Wear is tested by the Deval Abrasion Machine.



Abrasion Machine

This machine has been adopted by the United States Government and in several other countries as the standard. 5 kilograms (11 lbs.) of rock made up from 50 pieces each approximately 100 grams, are placed in a cylinder 20 c.m. diameter and 34 c. m. long (7.89″ x 13.39″) set at an angle of 30° and revolved for 10,000 revolutions at 30 to 33 revolutions per minute. Only the material worn off which will pass through a 0.16 c.m. (1/16 inch) mesh sieve is considered in determining the amount of wear.

The amount of wear is expressed either as the per cent of 5 kilograms (11 lbs.) used, or as a Coefficient of Wear.

The Coefficient of Wear is

$$\frac{20 \times 20}{W} = \frac{400}{W}$$

W being the weight in grams of the detritus per kilogram of rock used.

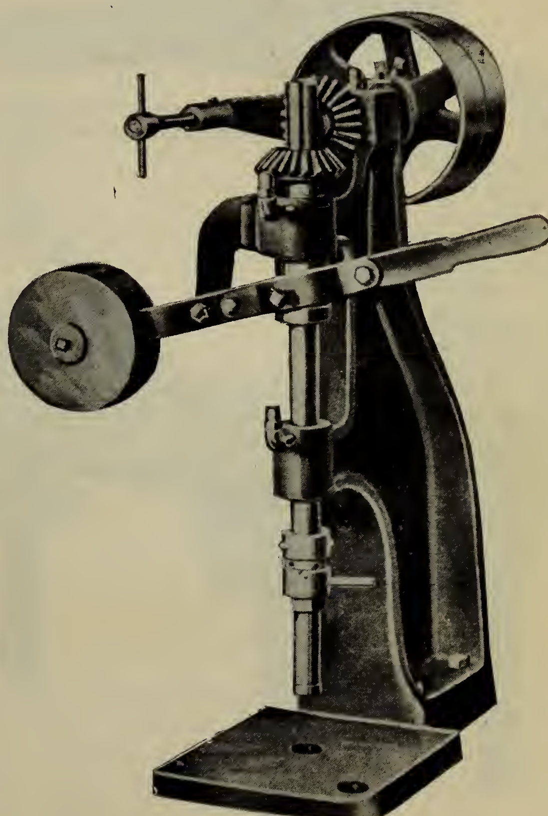
The United States Bureau of Roads interprets tests in the following way:

Coefficient of Wear.	Per Cent of Wear.	Quality.
Below 8	Above	Low
8 to 13	5% to 3.08	Medium
14 to 20	2.86 to 2%	High
Above 20	Less than 2%	Very High

Toughness Test:

This test is made in a machine adopted by the United States Government and the American Society for Testing Materials.

Toughness Machine

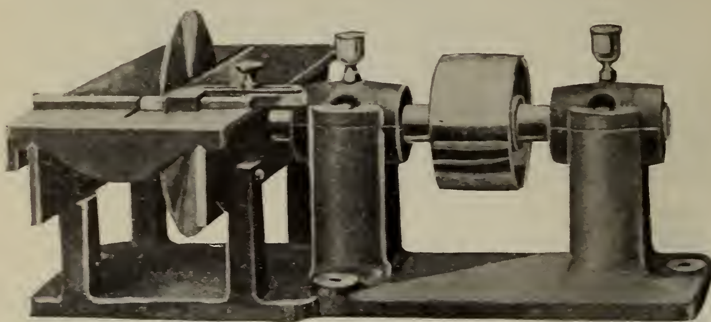


Diamond Core Drill

It consists of an anvil to which is connected the moving parts. A hammer of 2 kilograms (4.4 lbs.) weight is arranged so that it may be dropped by increments of 1 c.m. (0.39 inch) up to 90 c.m. (35.1 inches)

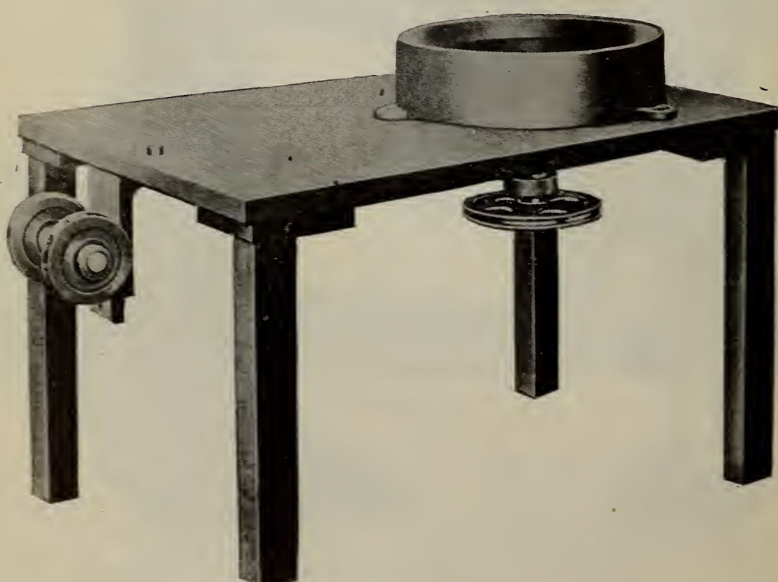
upon a plunger 1 kilogram (2.2 lbs.) weight which rests on the test piece. The test consists of 1 c.m. (0.39 inch) fall of the hammer for the first blow and an increased fall of 1 c.m. (0.39 inch) for each succeeding blow until failure of the test piece occurs. The number of blows to cause failure is used to represent the "Toughness" of the rock. The test pieces are 25 m.m. (0.984 inch) in diameter and 25 m.m. (0.984 inch) in height and cut out from rock by the Diamond Core Drill.

The ends are cut to the proper size by means of the Diamond Saw.

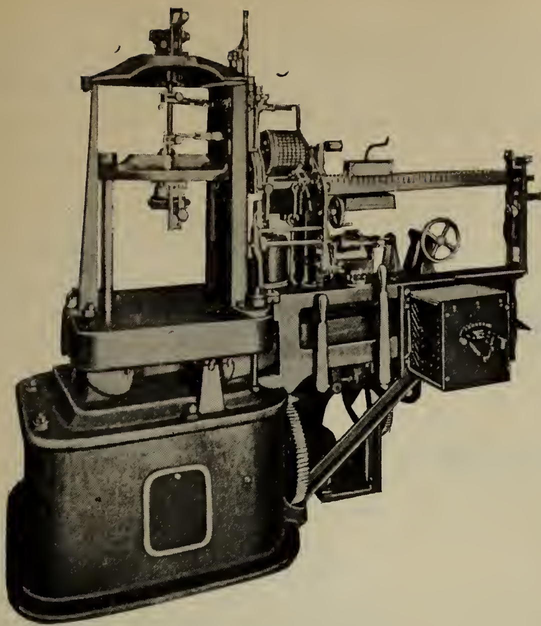


Diamond Saw

and squared and smoothed by means of the Grinding Lap.



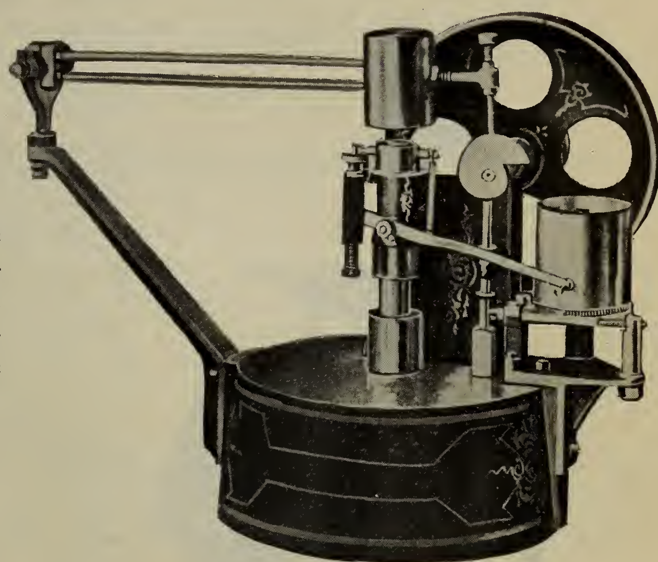
Grinding Lap



Compression Machine

Compression Test:

Test pieces 2″ diameter by 2″ high are placed in the machine and crushed and strength noted.



"Page" Impact Testing Machine

Cementation Test:

This test is made by means of a machine adopted by the United States Government as the standard.

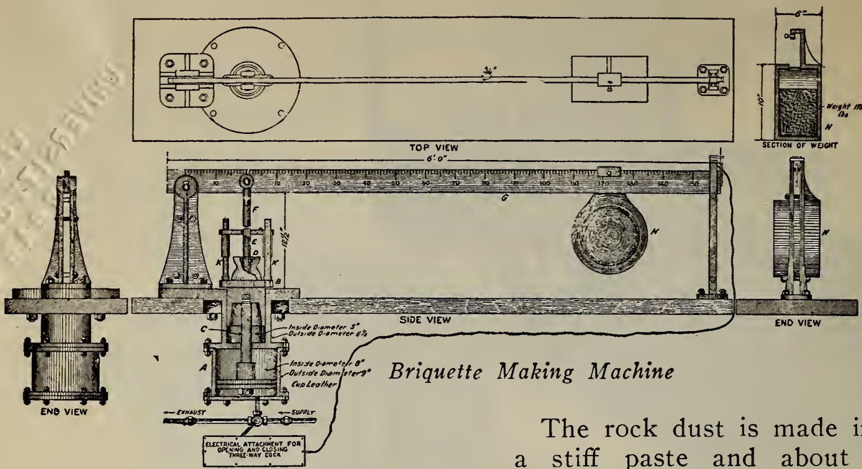
It consists of a hammer 1 kilogram (2.2 lbs.) in weight which is set at the first blow to drop 1 c.m. (.39 inch).) The hammer is raised by a cam and drops onto a plunger under which is the specimen resting on an anvil. The number of blows at which the specimen breaks is taken to represent the cementing value of the material.

The number of blows and the amount of resilence of the specimen at each blow, is recorded on a drum by means of a pencil attached to the plunger.

The number of blows is about 60 per minute.

Preparation of the Specimen.

The rock to be tested is put in the Deval Abrasion Machine and all dust under 16 mesh collected and used in making the briquettes.



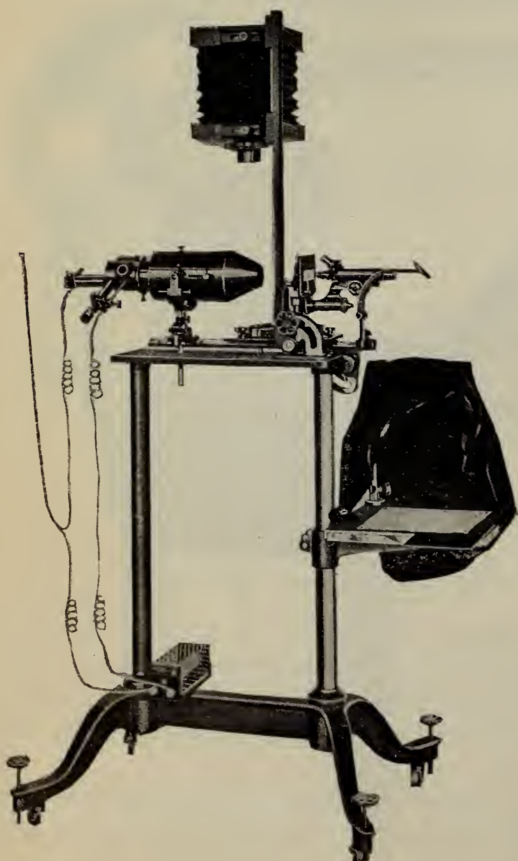
Briquette Making Machine

The rock dust is made into a stiff paste and about 30 grams put into a cylindrical mould. A close fitting plug is placed on the material and subjected to a pressure of 132 kilograms per square c.m. (1877 lbs. per sq. in.) or approximately a total pressure of 647 kilograms (1423 lbs.).

The briquette is allowed to dry 20 hours in air and 4 hours in a steam bath. It is then put in a dessicator to cool; 5 briquettes are made, each 25 m. m. (.98 inch) in diameter and 25 m.m. (.98 inch) in height.

Briquettes made in the same manner are tested for compression. This shows the behavior of rock dust cement under two different kinds of stresses: Impact and compression.

Cementation Value of the rock with asphaltum. The rock dust is mixed with the correct amount of asphaltum, usually from 11% to 13% of the weight of rock dust, and made into briquettes under the same pressure and conditions as the water and rock dust briquettes, with the exception of the dry-



Microscopic Apparatus

ing. These briquettes are allowed to dry in air for about three days, and are then put under the Impact Test and Compression Test before mentioned, and the relative value between water and asphaltum as a binder is determined.

CONCLUSIONS FROM ROCK TESTS.

Road building materials should not be selected by their mineral classification, for there is a wide variation in the qualities of the different outcrops and deposits of materials belonging to the same mineral class and type. They should be selected solely for their physical properties.

The physical properties which are of the most value in road building are in the following order of materials:

1—Trap.
2—Non-Crystalline Limestone.
3—Granite.
4—Mica Schist.
5—Quartzite.

The amount of wear allowable for road material where there is heavy traffic is 4%, and on roads of light traffic 5% of wear is permissible.

The number of blows under the Toughness Test should be 18.

Under Compression, the road material should not break under less than 20,000 lbs.

Cementing Value:

The United States Government has interpreted tests with water and rock dust in the following manner:

Number of Blows.	
0 to 10	Low
11 to 25	Fair
26 to 75	Good
76 to 100	Very Good
Above 100	Excellent

The rock to be used in a first-class road should not break at less than 25 blows. Under compression it should not be less than 200 lbs. per square inch. When made into briquettes with liquid asphaltum, it should not break with less than 750 blows, and under compression with less than 175 lbs. per square inch.

ASPHALTUM.

(CORRECTIONS IN PUNCTUATION)

Asphaltums are solid or semi-solid native Bitumens, solid or semi-solid Bitumens, obtained by refining petroleum, or solid or semi-solid compounds, which are combinations of the Bitumen mentioned, with petroleum or derivations thereof, consisting of a mixture of hydro-carbons of complex structure, largely cyclic and bridge compounds, melting upon the application of heat.

Asphaltic Petroleums are petroleums which yield asphaltums upon refining. Asphaltum cement consists of an asphaltum pure, mixed with foreign matter which may or may not be fluxed with petroleum residuums.

Bitumens are mixtures of native or pyrogenous hydro-carbons and their non-metallic derivatives, which may be gases, liquids, viscous liquids or solids, and which are soluble in carbon bisulphide.

The qualities Asphaltum should have are:

1st: It should bind materials together, i. e., should have adhesiveness.

2nd: It should be ductile.

3rd: It should not be brittle at low temperatures nor liquid at high temperatures.

There are both chemical and physical tests of Asphaltum.

CHEMICAL TESTS.

(A) Determination of the Amount of Bitumen: This test is made to determine the amount of foreign matter in the product. The mineral matter is a deleterious product. It detracts from the binding power and adds to the weight. One should get 99% pure Asphaltum.

(B) Determination of Bitumen Insoluble in Carbon Tetrachloride: The bitumen insoluble in carbon tetrachloride, but soluble in carbon bisulphide is commonly known as "Carbenes." These Carbenes are the result of overheating and are deleterious to the material.

(C) Determination of Bitumen Insoluble in 86° Beaume Paraffine Naphtha: The bitumens insoluble in paraffine naphtha, but soluble in carbon bisulphide are commonly known as Asphaltenes. This gives us an indication of the stability of the Asphaltum, though if the amount be very great, the life of the material has been impaired and the Asphaltum is less ductile. Besides this test, a 66° Beaume naphtha and a 72° Beaume naphtha are also made use of as solvents, for the purpose of determining the character of the bitumens in the Asphaltum.

(D) Determination of Fixed Carbon: The amount of the fixed carbon shows us the stability of the Asphaltum. The larger the amount of fixed carbon, the harder the Asphaltum, the higher the melting point, but the lower the ductility. This fixed carbon must not be confused with free carbon. Fixed carbon is the carbon which has been brought to coke by heating without the presence of oxygen, and is originally the carbon in the hydro-carbons. Free carbon exists as such in the material and is very deleterious.

(E) Determination of Paraffine Scale: Paraffine in an Asphaltum has a deleterious effect, as it has no binding power, but rather a greasy or lubricating power.

PHYSICAL TESTS.

Consistency: This test is the penetration test, and is made by determining the distance which a weighted needle will penetrate into the Asphaltum at a given temperature. A No. 2 cambric needle is used weighted with 100 grams for 5 seconds at 77°. It is a convenient test for identification and control, and indicates properties of value in construction work. If the

Asphaltum is too hard, it will become brittle and break. If too soft, it will run at high temperatures.

Float Test: Another method of testing consistency when the Asphaltums are too soft to obtain readings on the standard penetration machine, is the float test. This consists of an aluminum float with a plug of Asphaltum which is placed in water at a certain temperature. The time taken by the water to force out the block of bitumen and sink the float, is taken as a measure of the consistency.

Melting Point: There can be no true melting point of Asphaltum since it is a mixture of various hydro-carbons which have different melting points. So an arbitrary method is necessary.

Viscosity Test: This test is used to determine the degree of fluidity at a given temperature. Results are expressed as specific viscosity compared with water at 25° C. as follows:

$$\text{Specific viscosity at } a^\circ \text{ C.} = \frac{\text{seconds for passage of given value at } a^\circ \text{ C.}}{\text{seconds for passage of same value of water at } 25^\circ \text{ C.}}$$

Volatilization Test: Twenty grams of material are placed in an oven at a temperature of 163° C. for five hours, then the percentage of loss is determined. It is possible to tell from this test whether a straight refined product is used or a cutback product. The general appearance of the residue should be noted and the penetration taken.

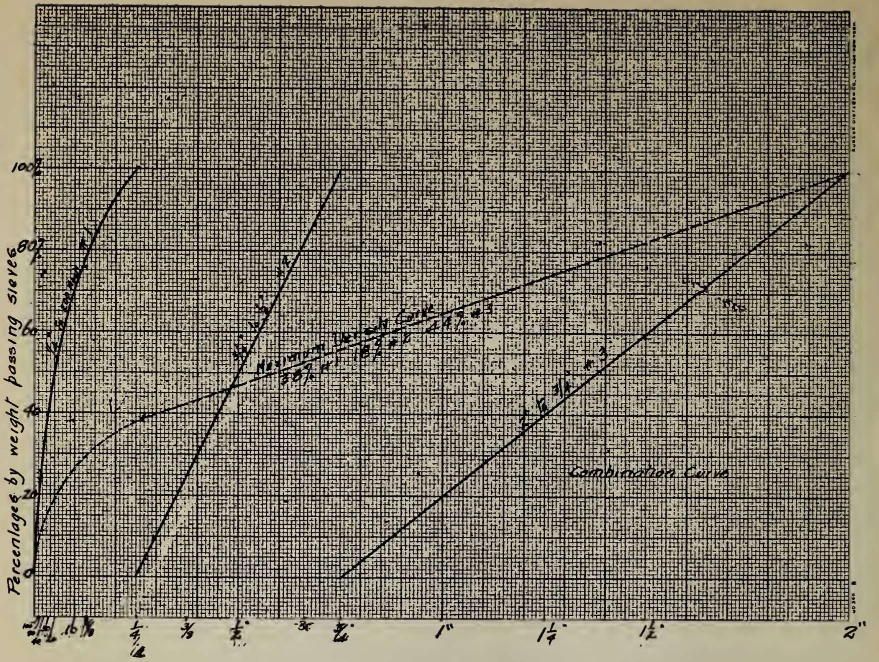
Ductility Test: This test is made by pulling out a standard Briquette of Asphaltum at a standard rate at a standard temperature. The distance it pulls before breaking is a measure of the ductility. This quality is most important in an asphaltum; it indicates that it will not become brittle at low temperatures, and also that is life is long.

NOTE: For details of the methods of carrying out these tests, see Bulletin No. 38, Office of Public Roads, United States Department of Agriculture.

PROPORTIONING MATERIALS.

In constructing a road of any mixture of materials whether concrete, asphaltum, asphaltic concrete, asphalt macadam, or water macadam, the densest and strongest mixture should be made.

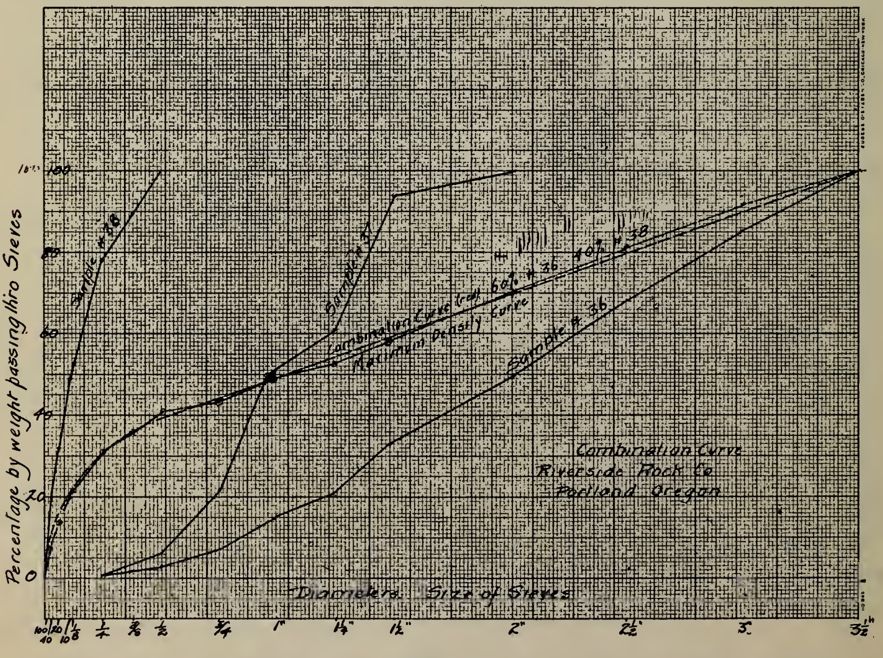
After years of experimenting in concrete asphalt and macadam work, a grading has been found which gives the strongest possible mixture and the least voids. It approximates a uniform percentage of each grade, according to its size, with the exception of the fines, which increase from 1/10 of maximum diameter of stone used down to fines. Also 7% of the total must be less than 200 mesh. The curve of this grading is a straight line down to 1/10 of maximum diameter of stone used, from that point it is an ellipse. This maximum density curve is illustrated in the following figure.



Curve of Maximum Density

The dotted line is the curve proper, and the full lines indicate the gradings of three equal parts of a total ideal mixture.

The methods of getting this grading, alter with the financial aspect of the situation and engineering conditions. In order to get the required density and to conform, as closely as practical conditions will permit, to the ideal curve of grading, samples are taken of the several sizes of material contemplated; their gradings are placed in the form of a curve as follows:



Grading Curves of Samples, and Combined Curve Showing Grading of Proper Mixture of Samples for Maximum Density

The proportions of the samples which will give the densest possible mixture are then determined.

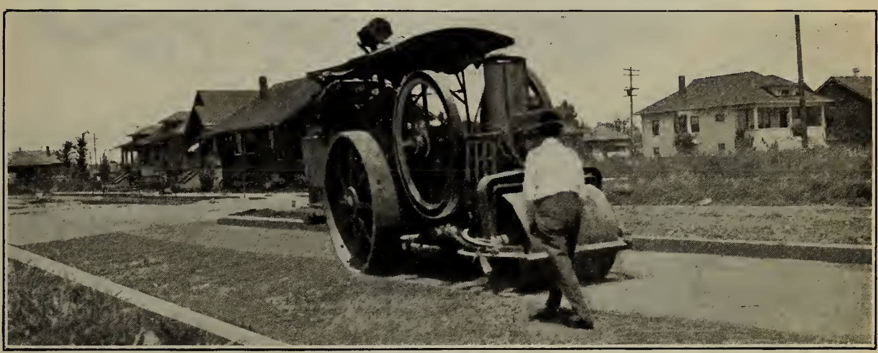
In the particular case noted above, 60% of sample No. 36 and 40% of sample No. 38, gives a curve lying close to the maximum curve.

METHODS.

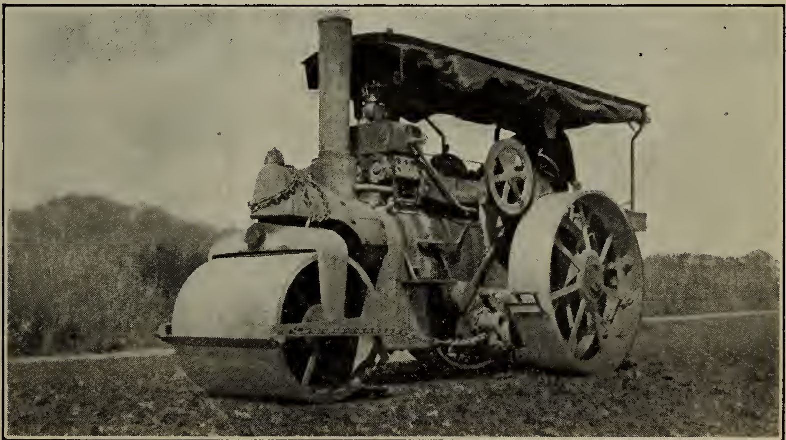
Sub-base: The sub-soil should be properly graded, watered and rolled until firm, to form a sub-base.

Base: The foundation or base of a road requires rigidity and strength. The usual materials employed are Portland cement concrete, or water macadam. In laying a concrete base the materials should be mixed in a mixer. Concrete when mixed should be deposited immediately without any separation of the ingredients. The concrete should then be thoroughly rammed and tamped until compact and the voids filled, which is evidenced by the water appearing on the surface.

In laying a water macadam foundation, the rocks should be spread in at least two layers, the larger rock for the first layer, and the smaller following in proportion to their sizes. The various layers should then be thoroughly mixed by harrowing or rolling or both.

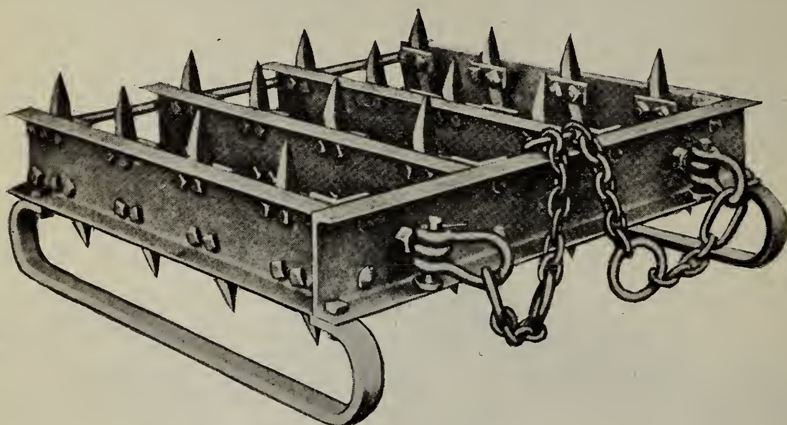


Ten Ton Gasoline Roller



Twelve Ton Steam Roller

Hand Roller



Heavy Road Harrow

Surface: In laying an Asphaltum wearing surface, two principles should be kept in mind.

1st: The mixture should be the densest possible.

2nd: The correct amount of Asphaltum should be thoroughly incorporated with the rock. If there is too little Asphaltum, the road will be dry with a tendency to crack; if there is too much, the road will be soft with a tendency to mushiness.

There are two methods of incorporating the Asphaltum with the rock: The Mixing method and the Penetration method.

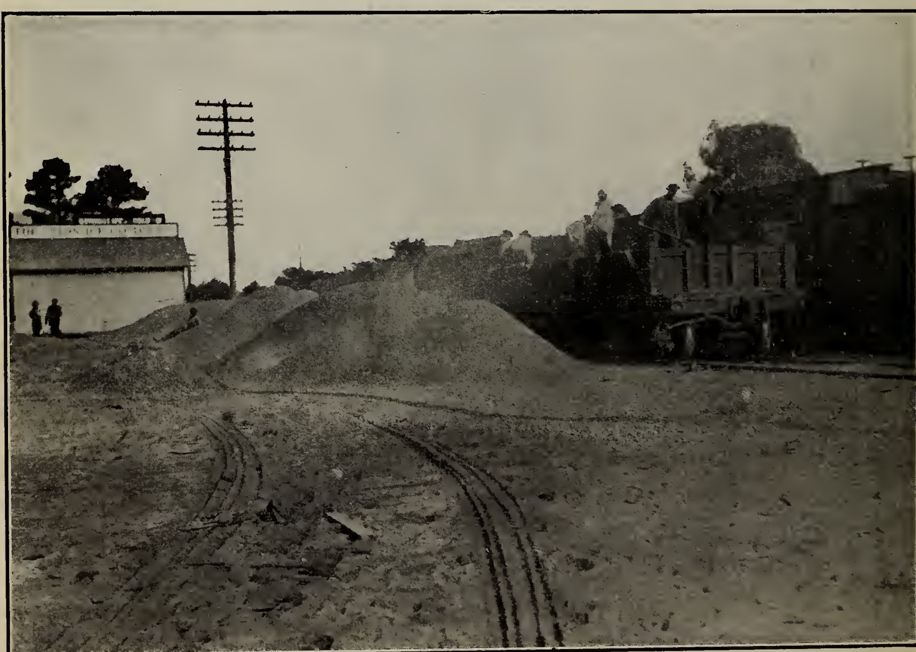
The Mixing Method comprehends the use of special devices for weighing and mixing the rock and asphaltum, and for spreading same on the road thereafter.

The first picture following illustrates a typical asphaltum plant; the right and left sides of picture are furnaces for heating asphaltum and rock respectively. From the furnaces the ingredients are carried to the mixing platform by machinery, where they are weighed on automatic scales, mixed in a powerful mixing mill and dumped into wagons below. The descriptive titles of the other pictures indicate each step of the process.

A Typical Asphaltum Plant

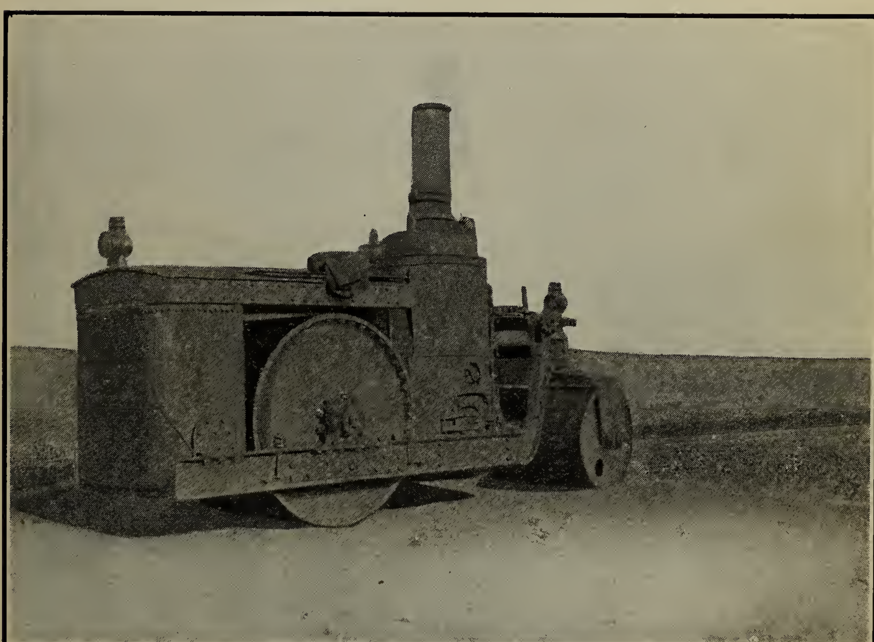
A Typical Asphaltum Plant in Course of Construction

A Stack of "Star Asphaltum"

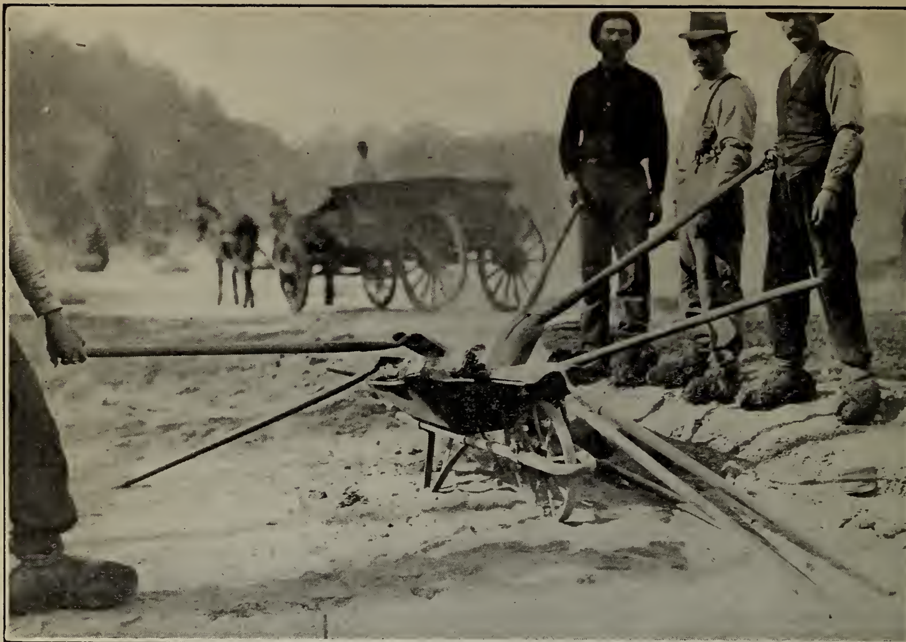


Unloading

Dump Wagon Loaded with Mixed Material



Rolling the Sub-base



Heating Tools to be Used

Spreading the Material

Material Ready to Rake

Raking the Material

Preliminary Rolling with Fire Roller

Finishing Rolling with Five-Ton Roller

Finished Road

The Penetration Method is accomplished by means of a sprinkling wagon equipped with power pumps which jet the asphaltum into the

Steam Power Sprinkler when Blowing Out with Steam Preparatory to Turning on the Asphaltum

material. It might be mentioned here that good construction does not permit the use of gravity sprinklers. Specifications for the penetration method vary. There should be at least two sprinklings, one on the top of the road base, which is covered with a certain amount of graded rock

Steam Power Sprinkler in Action

dependent upon local conditions, and successive sprinklings as conditions may require. Good results are obtained by the penetration method.

The various steps in the construction of a road by the penetration methods are shown in the following pictures with their descriptive titles:

Base Leveled to Grade

Crushed Rock Laid to Proper Depth Ready for Rolling

Crushed Rock Rolled

Star Asphaltum Applied to Top Layer of Rock with Power Sprayer, Forcing Asphaltum into Voids, Leaving a Minimum on the Surface

Top Layer of Rock Partially Covered with Star Asphaltum

Top Layer of Rock Rolled and Sprayed with Star Asphaltum Ready for Screenings

Completed Road Screened and Hot Rolled

SURFACING OF WATER MACADAM ROADS.

This may be done in two general ways according to the conditions of the road.

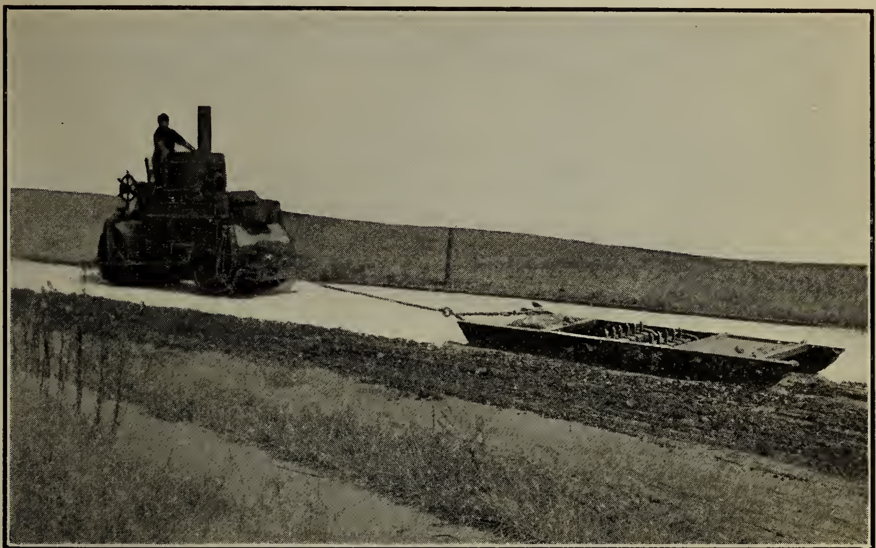
When the road is in good condition, that is, without ruts or pockets, the surface should be swept clean until the rock is bare. Asphaltum should then be applied at the rate of about one-half gallon per square yard. Then it should be covered with graded one-quarter inch rock and hot rolled until of a firm and uniform texture throughout.

When the road is in bad condition, having ruts and pockets, the surface should be swept clean and broken with scarifier to a depth of not more than one and a half inches, for the reason that the water bond should not be broken more than necessary, as it will not re-set with the same strength after once broken.

Scarifying Road to be Reconstructed and Repaired

Road After Being Scarified

One Type of Scarifier



Type of Road Plane for Leveling Roads to be Surfaced

The road should now be brought to its proper level by adding fresh material if necessary. Asphaltum should then be spread on at the rate of about three-quarters of a gallon per square yard. Screenings should then be put on and the whole thoroughly rolled, until the surface is firm and of a uniform texture.

AUTHORITIES.

CHEMICAL TESTS.

United States Department of Agriculture, Office of Public Roads, Bulletin No. 38.

Dust Preventives and Road Binders—Prevost Hubbard.

ROCK TESTING.

United States Department of Agriculture, Office of Public Roads, Bulletin No. 44.

PROPORTIONING MATERIALS.

For further detail of this, refer to the "Proceedings of the Society of American Civil Engineers," Volume 59, Page 67 (1907) and to Taylor and Thompson's "Plain and Reinforced Concrete."

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